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Climate Change Policies, Energy Security and Carbon Dependency

Trade-offs for the European Union in the Longer Term

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Abstract. Energy policy in the European Union (EU) faces two major challenges. The first challenge is posed by EUs commitment to reduce greenhouse gas emissions to the atmosphere in the context of the international agreement on climate change. The second challenge is to keep ensuring European security of energy supply, while its dependency on external sources of energy is projected to increase. In this paper, two long-term alternative climate change policy scenarios for Europe are examined. In the first scenario, EU reduces carbon dioxide emissions by domestic measures; in the second scenario EU maximizes cooperation with the countries of the former Soviet Union (FSU). Impacts on carbon flows between the EU and FSU and on the external energy dependency of the EU are assessed with an applied general equilibrium model, GTAP-E, whose set of energy commodities is expanded with combustible biomass as a renewable and carbon-neutral energy commodity. The results show that there is a trade-off between economic efficiency, energy security and carbon dependency for the EU. The FSU would unambiguously prefer cooperation.

Key words: biomass, carbon dependency, climate change policy, emissions trading, energy security

Abbreviations: C – Carbon; CO_2 – Carbon dioxide; ECCP – European Climate Change Programme; EU – European Union; EU28 – (Hypothetical) Enlarged European Union of 28 Member States; FSU – Former Soviet Union; GHG – Greenhouse gases; GTAP – Global Trade Analysis Project; GTAP-E – Global Trade Analysis Project model with energy substitution; Mt C – Million tons of carbon; Mtoe – Million tons of oil equivalent; RoA1 – Rest of Annex I; RoW – Rest of World; SSA – Systematic Sensitivity Analysis; Toe – Ton of oil equivalent; USD – United States' dollars; WEO2002 – World Energy Outlook 2002

1. Introduction

Energy policy in the European Union (EU) faces two major challenges. The first challenge is posed by EUs commitment to reduce greenhouse gas emissions to the atmosphere in the context of the international agreement on climate change. The second challenge is to keep ensuring European security of energy supply, while its dependency on external sources of energy is projected to increase (IEA 2002). These challenges to energy policy must be faced in a time when EUs markets of electricity and natural gas are in the process of being liberalized; when the EU is facing a major political challenge because of the upcoming accession of new Member States; and when the political stability in major energy-producing countries in the world is fragile and insecure.

This paper focuses on the interaction between the challenges of climate change and energy security to EUs energy policy in the longer term. The primary question is whether synergy is possible between climate change policies and energy security policies or whether these policies must necessarily conflict with each other. In particular, the paper examines two options for pan-European cooperation between Eastern and Western Europe on energy security and climate change policies in the longer term. In the first option, the EU tries to meet its reduction targets entirely by internal measures. In this way, the EU attempts to simultaneously reduce its carbon dioxide emissions and reduce its external energy and carbon dependency by actively promoting the indigenous production and use of renewable energy, in particular that of combustible biomass. In the second option, Eastern and Western Europe cooperate in climate change policies by establishing an international, unrestricted carbon dioxide emissions trading program between the two regions. The economic, energy and environmental effects of these two options are assessed with the help of an applied general equilibrium model of international trade that is calibrated to the parameters of the problem at stake.

The structure of the paper is as follows. Section 2 presents some background on EU climate change policies (Section 2.1) and energy security policies (Section 2.2). Section 3 discusses the model and the data. Section 4 specifies the policy scenarios. Section 5 presents the results of the simulations (Section 5.1), and interprets the results for the two policy scenarios (Sections 5.2 and 5.3). Section 5.4 introduces the concept of carbon dependency and quantifies the trade-off between energy and carbon dependency on the one hand and welfare on the other. Section 6 examines the sensitivity of the results to changes in parameter values, while Section 7 concludes and suggests areas for further research.

2. EU policies on climate change and energy security

2.1. Climate Change Policies

International climate change policies seem to be in a critical stage at the moment. It is still unclear whether the Kyoto Protocol will be ratified by enough Parties to come into effect, and which Parties will eventually aim to meet its targets. Moreover, there is little progress on the formulation of precise and operational definitions of the instruments of the Kyoto Protocol, including the trading mechanisms and sinks. It is extremely difficult at the present time to foresee the future development of the international climate change regime and its effects on material and virtual carbon flows among nations.

Nevertheless, it may be assumed as a working hypothesis, that an international climate change regime will unfold over this century. It may also be assumed that this regime will cover at least some industrialised countries and countries with economies in transition. Means will probably be found to engage developing countries in this regime, in one way or another. The bottom-line is that the external costs of carbon emissions (and emissions of other greenhouse gases) will be internalised into the economic process, to a greater or lesser extent. Given the differences in carbon content among different fuels and other energy carriers, this will lead to changes in production and consumption and international trade. For recent assessments of medium-term impacts of climate change policies on the European Union, see, for example, Böhringer (2002) and Viguier et al. (2003). For a broader analysis and discussion of legal, political and economic aspects of international climate change policies, see Ierland et al. (2003).

The European Commission has taken climate-related initiatives since 1991, when it issued the first Community strategy to limit carbon dioxide (CO_2) emissions and improve energy efficiency. These include a proposed directive to promote electricity from renewable energy, voluntary commitments by car makers to improve fuel economy and proposals on taxation of energy products. Proposals for policies and measures initially focused on the energy, transport and industry sectors, but the scope later broadened to encompass other sectors such as agriculture, forestry and waste. In a Green Paper on emissions trading the Commission set out its ideas on an internal EU-wide Greenhouse Gas (GHG) trading system. The Commission proposed that the EU trading system should initially focus on CO_2 emissions and involve only a relatively small number of economic sectors and sources that contribute significantly to emissions, but that the scheme could be broadened in future to include other GHGs and sectors. Several Member States have developed strategies to meet the targets set by the Kyoto agreements. Several Member states are also developing internal CO_2 trading systems as a part of these strategies (Zapfel and Vainio 2002).

International climate change policies and the implementation of these policies in the EU and its Member States can influence carbon flows between the former Soviet Union (FSU) and the (enlarged) EU. While there is uncertainty on the form that the international climate change regime will take, it is likely that both the international community and the EU will continue to develop and implement policies in this area.

Russia and other countries of the FSU could also play a role in EU climate change policies by increasing their supplies of fuels with a low or zero carbon content (gas, biomass). Whether this is an attractive option for the EU is also dependent upon other considerations such as, for example, energy (security) policies.

2.2. Energy Security Policies

Energy security is a complex and multi-faceted concept. It has been described as "one of the most overused and misunderstood concepts in the energy debate" (Helm 2002: 175). What is behind the idea of energy security is that rapid price changes of energy goods are usually very costly to modern economies due to large adjustment costs. Therefore, energy security policies typically aim at a diversification of energy sources (by type and origin) to reduce the risk of sudden shocks. However, different countries in different times have perceived the main risks to energy supply fundamentally different, so that in practice all sorts of policies have been justified in the name of diversity (Helm 2002). At the moment, EU energy security policy seems to perceive the greatest risks in the (rising) *external dependency* of the Community on energy resources (in particular: Middle East' oil and Russian gas) (EC 2001a). Forecasts predict that the EU's dependence on external sources will reach 70 per cent in 2030, and this situation will not improve by enlargement. Moreover, a number of EU member states, and in particular the applicant countries, are entirely dependent on a single gas pipeline that links them to a single supplier country.

One of the possibilities to reduce this external dependence might be the stimulation of the production of domestic sources of renewable energy. The objective of the EU is to double the share of renewable sources of energy in total primary energy demand from the present six per cent to twelve per cent by the year 2010 (EC 1997). Within this overall objective, an important role is foreseen for biomass. To stimulate the production of biomass several financial measures (aids, tax deductions, and financial support) are considered (EC 2001a: 5). Another possibility that was recently suggested by Huntington and Brown (forthcoming) is that countries may want to disproportionally reduce the carbon emissions of fuels with the largest import shares. This would reduce energy dependency and would also cut costs because of improvements in the terms of trade.[1]

EU energy policies are of major importance to the carbon flows between the FSU and the EU. In the first place, economic and technological options in the energy sector are of major importance for the cost-effective abatement of CO_2 emissions. Will Europe's energy future remain based on fossil fuels (possibly with technologies that capture and store CO_2 emissions due to combustion), or will a major switch to renewable energy sources take place? In the second place, what are the synergies and contradictions between climate change policies and energy security policies? Both climate change policies and energy security policies emphasize the importance of demand-side options with respect to energy savings. But climate change policies and energy security policies may contradict in the area of supply-side options, for example with respect to the production and use of coal, and with respect to the reliance on imports of cleaner fuels.

3. The model and data

3.1. GTAP-E Model

The numerical analysis in this paper employs the GTAP-E model (version 6.1.5), a member of the Global Trade Analysis Project (GTAP) family of models (Hertel

1997). The GTAP model is a widely used, comparatively static, multisector, multiregion applied general equilibrium model. Because it is comparatively static it calculates only distinct equilibrium positions of the economy, and not the path along which the economy moves from one equilibrium to the other. The model makes use of a detailed database with a broad coverage of (trade) distortions and explicit statistics on transport margins. Firms are assumed to use constant-returns-to-scale technologies, except for the energy supply sectors that have an upward-sloping supply function. Import demand is modelled through the Armington assumption of imperfect substitutability between domestic and imported goods and between imported goods from different regions. The Armington approach to import substitution is widely used in applied trade models. It treats goods from different countries as imperfect substitutes (or varieties), thus avoiding complete specialization of countries or unrealistically large trade responses to price changes. The model assumes a global bank to mediate between world savings and investments, and a region-specific set of equations for consumer demand that allows for different responses to price and income changes across regions. GTAP-E has the same structure as GTAP, but its production structure includes a more detailed description of substitution possibilities among different sources of energy. Burniaux and Truong (2002) give a full description of the model; see also the Appendix to this paper.

The GTAP-E model is calibrated on the GTAP-5E database. This database contains information on input-output relationships and bilateral trade flows among five factors of production, fifty traded commodities and fifty regions for the year 1997, expressed in million USD. In addition to the standard GTAP-5 database, the GTAP-5E database contains detailed information on the volumes of traded and used energy commodities (in million tons of oil equivalent) and on emissions of carbon dioxide (in million tons of carbon).

The GTAP-5E database does not contain information on renewable energy sources. For the simulations presented in this paper, we have added to the database information on biomass as a source of renewable energy. The Appendix to this paper contains a brief description of the sources of biomass information used and the methodology employed to integrate this information in the GTAP-5E database, while preserving its consistency.

Biomass is added to the set of non-electric, non-coal energy commodities in the GTAP-E model. Substitution possibilities among the energy commodities and among energy commodities and primary factors of production, such as capital, are determined by substitution elasticities. Because the present application deals with a long-term problem, the standard GTAP-E energy substitution elasticities have been doubled, and those that are relevant to the electricity sector have been quadrupled (Section 6 examines the sensitivity of the results with respect to the changes in these elasticities).

For our policy simulations, we have aggregated the GTAP-5E database into four regions and eight traded commodities (including biomass). The regions are: EU28 (see below), Former Soviet Union (FSU), Rest of Annex I (RoA1), and the Rest of the World (RoW). The sectors include six industries that produce energy commodities (coal, crude oil, gas, petroleum and coal products, electricity, and biomass), and two other industries: energy-intensive industries and the large residual sector of other industries and services. Table I presents an overview of the aggregated regions and sectors/commodities.

For the purposes of this paper, it is assumed that the EU will continue with the process of enlargement over the next decades. In our simulations the EU will expand towards a union of twenty-eight countries in the year 2030. This 'EU28' consists of the present fifteen member states of the EU plus the Eastern European accession countries (less the Baltic States),[2] the countries of the European Free Trade Area (Norway, Switzerland, Iceland), and Turkey.[3]

3.2. Base Data

Table II presents carbon flows between EU28 and FSU in the base year (1997). A distinction is made between the primary energy commodities coal, crude oil,

Table I. Aggregated regions and sectors/commodities.

Regions		Sectors/commodities	
EU28	E_U	Coal	Coal
Former Soviet Union	FSU	Crude oil	Oil
Rest of Annex I	RoA1	Gas	Gas
		Petroleum and coal products	P_C
		Electricity	Electricity
		Biomass	Biomass
Rest of World	RoW	Energy-Intensive Industries	En_Int_Ind
		Other Industries and Services	Oth_Ind_Ser

Table II. Carbon flows associated with international trade in energy commodities between EU28 and FSU.

	From FSU to EU28 (in Mt C)	From EU28 to FSU (in Mt C)
Coal	9.4	5.0
Crude Oil	71.6	0.1
Gas	49.5	0.7
Oil products	39.6	5.6
Fossil Fuels	**170.1**	**11.4**
Biomass	0.2	0.0
Total Carbon	**170.3**	**11.4**

Source: Own calculations based on GTAP-5E database and International Energy Agency.

gas, and biomass on the one hand, and refined oil products on the other hand. Table II shows that the trade balance is highly skewed, with a large net import of EU28. In terms of carbon, trade in crude oil and gas dominant, while international trade in biomass is very limited. The carbon flow from FSU to EU28 totals 170 million tons of carbon (MtC). There is also a much smaller carbon flow from EU28 to FSU of 11 MtC. In the remainder of this paper, we will not report the (small) changes in this latter flow.

3.3. Energy Dependency

Energy dependency can be expressed in many ways. In principle, there are as many different types of energy dependency as there are types of (imported) fuels. In this paper, the external energy dependency is defined as the ratio of *net* imports of primary energy resources (coal, gas, oil, and biomass) to total consumption of these resources in tons of oil equivalent (toe).

3.4. The Baseline Scenario

The baseline scenario that is used in the policy simulations is derived from the Reference Scenario of the 2002 World Energy Outlook (WEO2002) of the International Energy Agency (IEA 2002). The Reference Scenario is based on a set of assumptions on macroeconomic conditions, population growth, energy prices, government policies and technology over the period 2000–2030. The Reference Scenario takes into account all relevant government policies and measures that have been enacted as of mid-2002, and it is assumed that these policies and measures will not change over the projection period (IEA 2002).

Global economic growth over the period 2000–2030 is assumed to be three per cent per year on average. Global population growth is projected to slow down to an average of one per cent per year over the projection period. Most of global population growth is projected to occur in the urban areas of developing countries. World energy use is projected to increase steadily over the projection period. Fossil fuels will remain the primary sources of energy. Among the fossil fuels, natural gas will grow fastest, but oil will remain the most important energy source. The share of renewable energy sources will increase, while that of nuclear power will fall. The supply of oil and gas is increasingly concentrated in the Middle East and Russia, while additional demand is mainly from OECD and the dynamic Asian economies. Hence, international trade in energy commodities will expand, pushing "supply security back to the top of the energy policy agenda" (IEA 2002: 57).

Economic growth in the "enlarged EU" (EU28)[4] is projected to average two per cent per year, while population growth falls to an average of 0.1 per cent per year. Primary energy use is also projected to grow, at a rate of 0.8 per cent per year. The shares electricity and gas in final energy consumption are projected to grow, while the shares of oil and, particularly, coal will fall. Electricity generation will increase its use of gas and renewables, while it will make less use of oil, coal and nuclear. As a result of these trends, the emissions of carbon dioxide from the combustion of fossil fuels are projected to increase by almost 23 per cent over the period 2000–2030.

On the production side, the EU supply of fossil fuels is falling. The production of coal will fall and oil production in OECD-Europe is projected to fall by more than 60 per cent. The indigenous supply of gas is projected to fall slightly. The production of renewables, including biomass, is projected to increase. The increased demand for energy in OECD-Europe cannot be met from indigenous supply. Hence, the energy import dependency of OECD-Europe, especially for oil and gas will increase substantially. The Middle East will emerge as a major new supplier of gas to Europe, but the FSU will remain its largest single supplier (IEA 2002: 116). The imports of fossil fuels from FSU measured in carbon grow at an annual rate of 1.9 per cent, from 170 MtC in 1997 up to 319 MtC in 2030. However, IEA (2002) notes "the possible introduction of new policies to curb rising energy imports and CO_2 emissions is a critical uncertainty in Europe's energy outlook" (IEA 2002: 177).

Economic growth in the FSU[5] is projected to be 3.1 per cent per year over the period 2000–2030, and therefore substantially exceeds the growth rate of EU28. Population growth is negative, however, at –0.3 per cent per year. Total primary energy use is projected to increase by 1.3 per cent per year. The share of coal in total primary energy use is projected to decline, while the shares of oil and gas are projected to increase.[6] However, the changes in fuel mix are less extreme than in OECD-Europe. Carbon dioxide emissions are projected to increase by 47 per cent over the period 2000–2030.

On the supply side, oil and gas production are projected to increase, but these projections are highly dependent on the assumption of sufficient investments in development drilling and pipeline construction. If these investments come true, Russia will increase its exports of oil and natural gas – to Europe, but increasingly also to China and Korea.

For the baseline scenario of this paper, the WEO2002 projections are complemented with IEA information on the period 1997–2000, to construct projections for the period 1997–2030. Key assumptions on the baseline scenario for EU28 and FSU are summarized in Table III.

4. Policy scenarios

In this paper we investigate the implications of two alternative scenarios for development of carbon flows between the EU28 and the FSU to the 2030s. The assumed policy goal under each of these scenarios is a 30 per cent reduction in greenhouse gas emissions by 2030, using 1990 emissions as a baseline (cf. Berkhout and Smith, *this issue*).

Table III. Key variables for baseline scenario 1997–2030 (annual % growth rates).

Variable	EU28	FSU
Economic growth	2.1	3.0
Population growth	0.1	–0.3
Primary energy supply	0.8	1.3
Production of coal	–0.6	0.6
Production of oil	–3.4	2.0
Production of gas	–0.3	1.6
Production of biomass	2.3	–0.0
CO_2 emissions fossil fuels	0.6	1.2
Carbon (import) flow	1.9 (from FSU)	0.6 (from EU28)

The two scenarios are:

a. *Autonomy/independence*: a scenario under which carbon flows are limited as part of a EU-wide energy policy to reduce dependency on extra-EU sources and to support a climate policy emphasising intra-EU energy sector adjustments and innovation.
b. *Trading/interdependence*: a scenario under which carbon flows are maximised as part of a general emphasis on free trade and liberalisation, and as a way of reducing the costs of carbon reduction.

In order to tentatively explore the consequences of these alternative scenarios a number of simplifying assumptions have been made.

(1) The climate change policy goal of –30 per cent applies to carbon dioxide only. We thus avoid complications by other gases and sinks.
(2) The policy goal of –30 per cent applies to EU28 only; FSU is assumed to stabilize its emissions at 1990 levels, and the other regions are assumed not to have any climate change policy goals at all (but see Sensitivity Analysis in Section 6).
(3) The difference between the scenarios described above is completely determined by the adoption of different sets of policy measures by EU28 and FSU in the respective scenarios.
(4) The policy measures themselves are stylised, *Idealtypisch*, and not bedraggled by the imperfections of political and economic reality.
(5) It should be emphasized that while the baseline scenario assumes fairly large rates of technological progress and learning with respect to energy efficiency and the generation of renewable energy, the policy scenarios do not assume that these rates will increase *because* of the climate change policies. In other words, no *induced* technological progress and learning is assumed in the policy scenarios. This is, of course, a conservative assumption that may overestimate the compliance costs of carbon reduction policies in the future.

In the *Autonomy/independence* scenario, EU28 adopts purely domestic measures to meet its CO_2 reduction target. It establishes a domestic emissions trading system, but permits cannot be exchanged across borders between the two regions. In order to stimulate intra-EU energy sector adjustments and innovation, and to reduce dependency on extra-EU sources of energy, EU28 stimulates the indigenous production of biomass for energy by way of an output subsidy and limits imports of biomass by means an import tariff.[7]

The policy measures in the *Trading/interdependence* scenario consist of the creation of a tradable emission permits system across the entire pan-European region. One permit grants the holder of the permit the right to emit one unit of CO_2. The permits are initially bought at an auction and can afterwards be freely bought and sold on secondary markets. The total number of permits that is put on the market is equal to *the sum of* the allowable CO_2 emissions of EU28 and FSU. The market determines by what proportion each region reduces its emissions.[8] In this scenario it is further assumed that trade-distorting subsidies on coal production in EU28 are eliminated.

The key assumptions of the two policy scenarios are summarized in Table IV.

5. Results

5.1. Carbon Flows and Energy Dependency

The *Autonomy/independence* scenario and the *Trading/interdependence* scenario represent two extremes in which EU climate policy could develop. As expected, carbon flows between the FSU and EU28 are affected by the choice of policy scenario. We make a distinction between tangible flows of carbon, associated with energy commodities, and intangible flows, associated with the international transfer of emission allowances. Figure 1 below shows the size of these tangible and intangible flows from FSU to EU28 in the two scenarios in 2030.[9] For comparison, Figure 1 also shows the carbon flows of the base year 1997 and the

Table IV. EU28 policies and measures in the two policy scenarios.

Policies/measures	Autonomy/independence	Trading/interdependence
CO_2 emissions reduction in comparison to 1990	–30%	–30%
CO_2 emissions trading	Within EU28 only	Within and between EU28 and FSU
Subsidy for indigenous biomass production	Output subsidy and import tariffs on biomass	None
Subsidy for EU coal production	Maintained	Eliminated

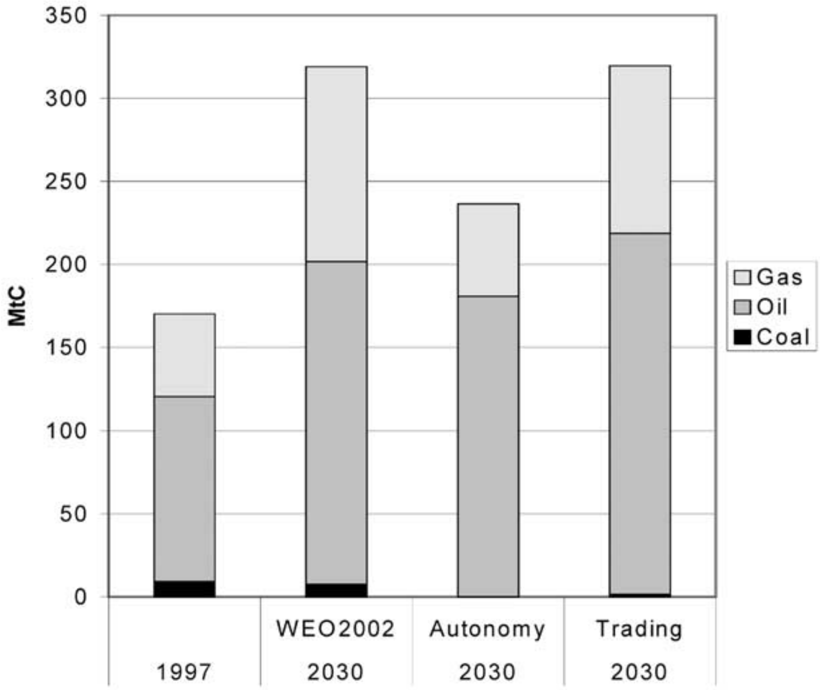

Figure 1. Tangible carbon flows from FSU to EU28 in three scenarios.

flows in 2030 as they would become if the EU would not taken action to reduce CO_2 emissions (the WEO2002 reference scenario). Without CO_2 reduction measures, the carbon flow from FSU to EU28 would increase from 170 Mt C in 1997 (see Table II) to 319 Mt C in 2030, a rise of 88 per cent. Among the fuels, the largest increase is for gas, followed by oil (crude plus oil products). The carbon flow associated with the export of coal to Europe decreases. The situation is radically different in the *Autonomy/independence* scenario. The carbon flow from 1997 to 2030 only increases by 39 per cent to 237 Mt C. There is also a difference in the composition of the fuel exports, as oil is now by far the biggest grower. The export of coal has become so small that it is no longer visible in Figure 1. In the *Trading/interdependence* scenario, the carbon flow is quite different again. The total tangible carbon flow is similar to the WEO2002 reference scenario, but the composition of fuel exports is quite different with oil now exhibiting the largest growth (as opposed to gas in WEO2002). In addition, the *Trading/interdependence* scenario shows a large intangible flow of carbon of 227 MtC in the form of emission allowances that are transferred from FSU to EU28.

How do these different scenarios affect the external energy dependency of EU28? Table V shows the energy dependency ratios for EU28 in the three scenarios. The first row shows the overall, global, energy dependency ratios of EU28, the second row shows EU28's energy dependency ratios vis-à-vis the FSU.

Table V. Energy dependency ratios of EU28 in three scenarios vis-à-vis World and FSU.

Vis-à-vis	WEO2002 %	Autonomy/independence %	Trading/interdependence %
World	67.8	65.6	70.3
FSU	12.7	12.2	16.3

The changes in trade flows in the *Autonomy/independence* scenario are induced by changes in production and consumption of carbon in EU28. In the *Trading/interdependence* scenario they are induced by changes in production and consumption in both regions and are therefore more difficult to explain. We start with the simplest case: the *Autonomy/independence* scenario.

5.2. *Autonomy/Independence* Scenario

EU28 reduces its emissions of carbon dioxide to a level that is 30 per cent below its 1990 emissions level of 1208 MtC. Compared to EU28's WEO2002 reference level in 2030 of 1453 MtC, this is a reduction of 41.8 per cent. FSU commits to stabilize its emissions at 1990 levels, but since the WEO2002 reference level does not exceed the 1990 level in 2030, no active reduction policy is required by FSU. It is assumed that EU28 has by 2030 established an emissions trading system that encompasses all sectors in all EU28 member states. Firms and private households require allowances for the combustion of fossil fuels. Hence, electricity producers are required to hold allowances for the fossil fuels they combust, but their customers are not required to hold allowances for their consumption of electricity. On the other hand, oil refiners are not required to hold allowances for the crude oil they transform into oil products, but their customers do need to hold allowances for the oil products they combust. Allowances for the annual emission of 846 million tons of carbon[10] are sold at annual auctions at an equilibrium price of € 152 per ton of C (= € 41.5 per ton of CO_2). Revenues of the auctions are rebated to households in a lump-sum fashion.[11]

In order to boost the production and consumption of renewable energy, EU28 subsidizes domestic biomass production. In order to avoid 'leakage' of this subsidy to foreign producers, and in order to enhance energy self-sufficiency within EU28, an import tariff on biomass is established that effectively 'freezes' import of biomass at pre-policy levels.

The high price for carbon allowances causes dramatic changes in energy production, consumption and trade. Total demand for fossil fuels drops, especially the demand for coal (–90%). Demands for oil and gas fall too. Although carbon emissions per unit of energy are higher for oil than for gas, the demand for oil (–12%) falls less than the demand for gas (–50%). This somewhat counter-intuitive result can largely be explained by the difference in initial taxation of gas and oil products in EU28. Oil products are heavily taxed, resulting in consumer prices that are more than four times as high as market prices. In contrast, consumer prices of gas are only one-and-a-half times as high as market prices. While the amount of carbon allowances that is required for the combustion of oil products exceeds those of gas *per energy unit*, their impacts on the consumer price of oil products are less than on the consumer price of gas. In the *Autonomy/independence* scenario the consumer price of gas rises by 58 per cent while the consumer price of oil products rises only by 15 per cent. Hence, all else equal, demand for gas falls more than the demand for oil products. And this is indeed the result that was shown above and that also explains the relatively small effect on the carbon flows in Table V associated with oil and oil products and the relatively larger negative effect on the carbon flows associated with gas.

The high initial taxes on oil products also cast doubts on the claim of Huntington and Brown (forthcoming) that a relatively high carbon taxation of imported fuels might be in the economic interest of countries due to terms of trade advantages. It is probably no coincidence that fuels with the highest import shares are already heavily taxed in many countries. High initial taxes make policies aimed at a further reduction of consumption of these fuels very costly from a welfare point of view.[12]

Demand for biomass depends on its rate of output subsidy. With no additional subsidies, demand for biomass increases by six per cent relative to the WEO2002 reference. Because the demand for fossil fuels declines, the share of biomass in primary energy supply increases significantly. In electricity generation, the share of biomass in primary energy supply increases from 2.5 percent in the WEO2002 reference to 22.0 per cent. Subsidizing biomass production increases the share of biomass in primary energy supply even further. A 100 per cent subsidy, as in the *Autonomy/independence* scenario, raises the share of biomass in electricity generation to 33.9 per cent.

But what are the benefits of this increased use of biomass? With the emissions trading system in place, total emissions of CO_2 are determined by the fixed quantity of allowances offered for sale. Under these circumstances, increased use of biomass does not reduce total carbon emissions. Increased use of *domestically produced* biomass could, however, lessen EU28's energy dependency. Figure 2 shows the relationship between the amount of biomass subsidy and energy dependency of EU28.

Figure 2 shows that energy dependency (Y-axis) is a decreasing function of the subsidy amount. The rate of decrease becomes smaller as the amount of the subsidy increases. The four diamonds in Figure 2 show energy dependency at subsidy rates of 0%, 50%, 100%, and 150% respectively. At these subsidy rates, energy dependency of EU28 drops from 67.6%, to 66.1%, to 65.6%, and finally to 65.4%. The X-axis of Figure 2 shows the total expenditure on subsidy. The 100% subsidy, as in the *Autonomy/independence* scenario, requires an annual expenditure of around € 7 billion.

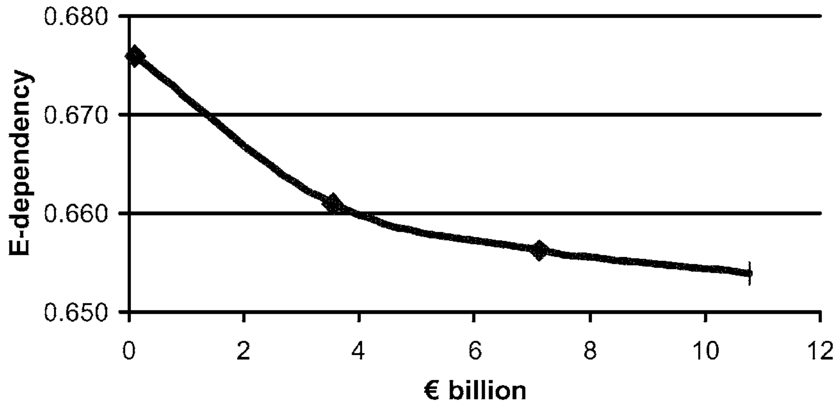

Figure 2. Biomass subsidy and energy dependency.

The 100% biomass subsidy thus reduces energy dependency by 2 percent-points. The biomass subsidy does not, however, affect carbon flows significantly. The reason for this is that the induced substitution effect (away from fossil fuels and towards biomass) is counterbalanced by an equally important "income" or "output" effect which allows more energy to be used because the subsidy makes the price of energy as a whole (the composite energy good) relatively cheaper. The subsidy enables EU28 to use more energy without violating the binding CO_2 constraint to which it has committed to by its climate policy. Energy dependency falls not because less energy is imported, but because more energy is domestically produced.

5.3. *Trading/Interdependence* Scenario

The *Trading/interdependence* scenario is clearly quite different. In this scenario, emissions trading is expanded over the entire pan-European region. The rules for emissions trading are the same as laid out in Section 5.2 for the *Autonomy/independence* scenario; the only difference is the wider geographical region of application. The result is that relatively cheap abatement options in the FSU can now be exploited by EU28 firms and citizens. Marginal abatement costs (and the price of CO_2 allowances) drop dramatically from € 152 to € 63 per ton C (or from € 42 to € 17 per ton CO_2). More than 42 per cent of the emissions reduction is now carried out in the FSU, financed by the sale of CO_2 emissions allowances to EU28.

The contribution of the elimination of coal subsidies in EU28 in this scenario is relatively minor. Without this elimination, the price of CO_2 emissions allowances would have been slightly higher. Nevertheless, the elimination of these *perverse* subsidies under the present scenario assumptions generates a welfare gain to EU28 of € 21 million.

Figure 1 showed that the tangible carbon flow between FSU and EU28 is maintained at its WEO2002 reference level in the *Trading/interdependence* scenario, and is even slightly above this level. This is perhaps a bit surprising as total energy demand in EU28 falls by about a quarter. Although EU28 engages in emissions trading with FSU, it still reduces CO_2 emissions at home by 26 per cent. All else equal we would expect imports of energy resources to fall by about a quarter too. Table VI shows that overall energy imports of EU28 fall by 18 per cent (first column). Table VI also shows, however, that the change in import demand vastly differs among regions and that import demand from the FSU slightly increases. The primary reason for these differences is the carbon reduction measures that are taken in the FSU in the context of the emissions trading scheme and that reduce the demand for energy in the FSU by about a quarter too. As a consequence of this reduction in demand, domestic prices for energy commodities fall in the FSU and exports become relatively more attractive, including exports to EU28.

Hence, although overall import demand of energy commodities by EU28 falls in the *Trading/interdependence* scenario, the price changes of energy commodities that result from emission reduction measures in the FSU cause exports from the FSU to be maintained at their pre-policy levels. The relatively lower import prices of energy commodities from the FSU also explain the increase in energy dependency in the *Trading/interdependence* scenario that was shown in Table V. The increase in energy dependency to 70.3 per cent can be explained by increased imports from the FSU.

The size of the carbon flow between FSU and EU28 is also affected by the financial transfers that are a consequence of the purchase of emission allowances by EU28. How does EU28 finance the purchase of these emission allowances? EU28 could draw on its official reserves in its Central Bank, but that would not qualify as a sustainable policy. The only other way for the EU28 to finance these foreign allowances is to create a surplus on its current account; that is to create a surplus in its international trade in goods and services. In order to do so, EU28 has to depreciate its currency so as to make its exports cheaper on the world market

Table VI. Change of import demand of EU28 by fuel and region.

Change in import demand from:				
	World (%)	FSU (%)	RoA1 (%)	RoW (%)
Coal	–80.9	–79.3	–86.3	–86.7
Oil	–4.0	15.6	–13.1	–9.1
Gas	–27.8	–14.1	–42.0	–37.3
Total *	–18.3	0.7	–83.8	–17.7

* Weighted by source at world prices.

and to make its imports more expensive.[13] This depreciation limits total imports of EU28, including the imports of energy commodities from the FSU. Numerical analysis with GTAP-E showed that this effect indeed occurs in the *Trading/interdependence* scenario. Without any *balance of payment* constraint, the associated carbon flow from FSU would be 6 per cent higher at 339 Mt C. However, EU28 would then run a current account deficit of € 3.7 billion. In the *Trading/interdependence* scenario it is assumed that EU28 finances its purchase of foreign emission allowances by creating an appropriate surplus on its current account, thus limiting overall imports and limiting carbon flows to the magnitudes depicted in Figure 1.

5.4. Carbon Dependency and Welfare Costs

Table V above showed how the different climate change policy options that make up the two scenarios affect energy dependency of EU28. Without any climate change policies energy dependency of EU28 would rise from 40 per cent in 1997 to almost 68 per cent in 2030. In the *Autonomy/independence* scenario, energy dependency falls to 66 per cent. Figure 2 showed the relationship between the energy dependency ratio and subsidies on domestic biomass production. In the *Trading/interdependence* scenario, the energy dependency ratio rises to more than 70 per cent. This is not the end of the story, however. In the *Trading/interdependence* scenario, the EU28 is also dependent upon the external supply of carbon credits or allowances. A volume of 227 MtC of emission allowances is transferred from FSU to EU28. Let us call the external dependency on emission allowances "carbon (trading) dependency". Carbon (trading) dependency can be defined as the ratio of net import of carbon allowances to total consumption of energy commodities in terms of carbon. We now have two types of external dependency ratios with respect to the consumption of energy: energy dependency and carbon (trading) dependency. Table VII compares these dependency ratios to the money metric of the welfare costs of the climate change policy options in both scenarios and for both regions.[14]

In the *Autonomy/independence* scenario energy dependency and carbon dependency of EU28 is around 65 per cent in 2030. Welfare costs for EU28 are almost € 95 billion. Table VII also shows that the welfare costs for RoW are negative in this scenario. Only RoA1, who, by assumption, implement no CO_2 reduction measures, benefits from EU28s policy measures. In the *Trading/interdependence* scenario, the carbon dependency of EU28 is 21 per cent. The welfare costs under this scenario for EU28 are almost half of those under the *Autonomy/independence* scenario. Global welfare costs are only 40 per cent of those under the *Autonomy/independence* scenario. Especially FSU benefits from the emissions trading in the *Trading/interdependence* scenario. While it suffers an annual welfare loss of € 5.4 billion under the *Autonomy/independence* scenario, it enjoys a welfare gain of € 12.0 billion under the *Trading/interdependence* scenario.

Table VII. Trade-off between energy dependency and climate change policies.

	Autonomy/independence	Trading/interdependence
Energy-dependency (%)	65.6	70.3
Carbon trading dependency (%)	0.0	21.2
Welfare costs (€ bn) to		
EU28	–94.6	–49.7
FSU	–5.4	+12.0
RoA1	+3.2	+2.3
RoW	–11.1	–8.0
WORLD	–107.8	–43.4

6. Sensitivity analysis

It is good practice to assess the sensitivity of the results CGE models with respect to key assumptions on parameters and design issues. This section assesses the sensitivity of the main results of the previous section with respect to (i) the elasticity of substitution among fuels and between energy and capital (energy substitution); the elasticity of substitution between domestic and foreign supply and among alternative foreign supplies (trade substitution); and the sensitivity of the results with respect to assumptions on emission reductions in other Annex I regions (RoA1 reductions).

For the sensitivity analysis use was made of the Systematic Sensitivity Analysis (SSA) feature of GTAP (Arndt 1996). SSA reports the sensitivity of model outcomes to parameters and policy shocks in terms of means and standard deviations (S.d.).

(1) The carbon flow between the FSU and EU28 is moderately sensitive to changes in the model's energy substitution parameters. Assuming a normal distribution for the carbon flow value, one can be 95% confident that its value will be between plus or minus two standard deviations of the mean, i.e. between 232 and 241 MtC in the autonomous scenario (its simulation value was 237 MtC) and between 315 and 325 MtC in the trading scenario (its simulation value was 320 MtC). The shadow price of carbon emissions is also moderately sensitive to changes in energy substitution parameters. The rate of energy dependency is only slightly affected by changes in these parameters.
(2) The model's outcomes are not very sensitive to changes in trade elasticities, with the exception of the carbon flow in the trading scenario, which is moderately sensitive to such changes.
(3) Carbon reduction policies of other Annex I regions increase the shadow price of CO_2 emissions in EU28 and increase energy dependency (as the import of energy resources (e.g. oil) becomes cheaper), but they reduce the mean carbon flow between FSU and EU28 (from 236 to 228 MtC). The standard

deviations show, however, that the model outcomes are fairly robust towards changes in climate policies in other Annex I regions.

The sensitivity analysis gives some confidence in the "robustness" of the model outcomes to changes in key parameter values. It also shows that carbon reduction policies in other Annex I regions do not radically change the results.

7. Conclusions

The design of Europe's future climate change policies has major impacts on a number of policy variables. Without additional climate change policy measures, the external energy dependency of the expanded EU, EU28, would rise from about 40 per cent in 1997 to almost 70 per cent in 2030. FSU remains a major import source of gas and oil. European climate change policies can affect carbon flows between EU28 and FSU and Europe's overall external energy dependency. If EU28 pursues major reductions of its CO_2 emission by domestic measures alone, the carbon flow from FSU would diminish. A domestic EU system of emissions trading would have a larger effect on gas imports than on oil imports, because of its relatively high initial taxation of oil products. EU28 could marginally reduce its external energy dependency by subsidizing the domestic production

Table VIII. Sensitivity analysis on key parameters and policy shocks*.

	Autonomous scenario			Trading scenario		
	Carbon flow FSU-EU in 2030 (MtC)	Energy dependency (%)	Price of CO_2 €/tCO_2	Carbon flow FSU-EU in 2030 (MtC)	Energy dependency (%)	Price of CO_2 €/tCO_2
1. Sensitivity to assumptions on the elasticity of energy substitution (±50%)						
Mean	236.4	65.6	41.8	320.0	70.3	17.2
S.d.	2.3	0.2	3.3	2.6	0.3	0.8
2. Sensitivity to assumptions on trade elasticities (±50%)						
Mean	236.5	65.6	41.4	319.5	70.3	17.1
S.d.	0.8	0.4	0.2	3.0	0.2	0.2
3. Sensitivity to assumptions on RoA1 reductions (0 to 100% of EU reductions)						
Mean	228.3	66.8	43.4	314.6	71.5	18.0
S.d.	3.2	0.3	1.0	1.3	0.2	0.3

* Sensitivity analysis performed with the method of "Gaussian Quadrature". Energy substitution parameters (ELKE, ELCO, ELLY, ELFY) and trade substitution parameters (ESBD, ESBM) range over ±50% of their simulation values, assuming a triangular distribution around the mean. Carbon reduction targets in RoA1 range over zero to one hundred percent of actual EU28 reduction percentages, also assuming a triangular distribution.

of renewable energy sources, such as combustible biomass. Our simulations suggest, however, that this may be a costly policy.

A pan-European system of emission trading, including FSU, would dramatically reduce CO_2 permit prices and the overall welfare costs of climate change policies. However, EU28s external energy dependency would increase. Next to its dependency on foreign energy, EU28 also becomes (heavily) dependent upon the external supply of carbon allowances.

In the final analysis, the preference of FSU for cooperation in climate change policies seems unambiguous. For EU28, the preference for cooperation seems undisputable from an economic perspective. However, our analysis suggests that efficient climate change policies increase energy dependency and, especially, carbon (trading) dependency. Hence, energy security policy is unlikely to free ride on climate change policy and this needs to be taken into account in the formulation of such policies.

The present analysis was based on a number of simplifying assumptions. One assumption was that only EU28 and FSU would continue with climate change policies, while the other world regions would not. It might be potentially interesting to relax this assumption and to examine alternative global CO_2 reduction scenarios. Also in the integration of biomass in the GTAP-E model and database, a number of simplifying, and perhaps arguable, assumptions were used. In further work, some of these assumptions, for example on technology, prices, and substitution elasticities, could be examined and refined. Finally, a dynamic representation of technology development under different policy scenarios could potentially generate interesting insights.

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Appendix: Integrating biomass in the GTAP-5E database and model

The primary database of GTAP-5E is expressed in monetary values (in millions of ^{1997}USD).[15] Energy commodities are also expressed in volume units (million tons of oil equivalent Mtoe). For this application I added data on biomass energy. Volume data were taken from IEA energy balances. Imports and exports of biomass energy were balanced in such a way that global imports equal global exports in the base year.

Value data (in millions of 1997USD) were calculated using the assumption that the price of combustible biomass per ton of oil equivalent (toe) is equal to the price of coal per toe (about 50 USD per toe depending on region and demanding sector). It has also been assumed that the input vector for biomass is proportional to the input vector for agriculture [because of this and the fact that identical substitution parameters are used, the production technology of biomass energy is identical to the production technology of agriculture]. Moreover, taxes and tariffs on biomass are identical to those on agriculture. Consistency of the database was preserved by subtracting the added biomass values from the original agriculture values (both for inputs and outputs). Finally, it has been assumed that "electricity" is the only sector that imports biomass.

In the GTAP-E model, biomass is included in the set of non-coal, non-electricity energy commodities. Figure A1 depicts the production structure of GTAP-E with biomass in a slightly simplified manner.

The various inputs in production are combined through CES functions, with substitution parameter σ. For the energy inputs into production, the values of the substitution parameters are shown in Table A1.

Model files can be found on URL: http://130.37.129.100/english/o_o/instituten/IVM/research/ihdp-it/implementation/index.htm.

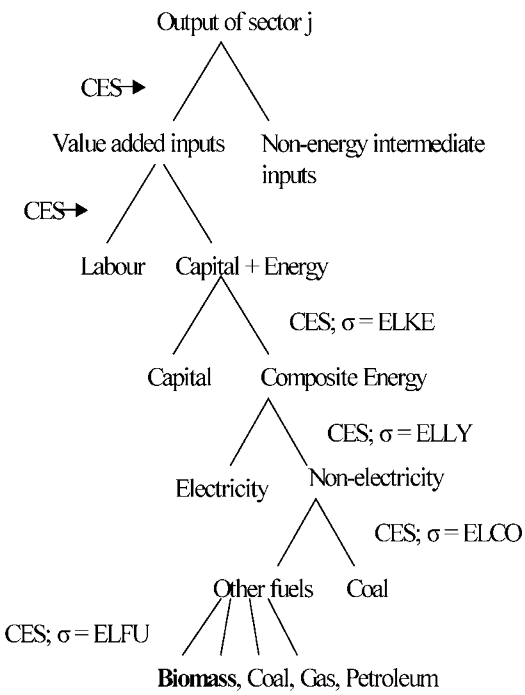

Figure A1. Production structure of GTAP-E with Biomass (simplified).

Table A.1. Substitution parameters in the production function.

Substitution parameter	Substitution between:	Value in EU28		In other regions
		In electricity	In other sectors*	
ELKE	Composite energy and capital	2.0	1.0	0.5
ELLY	Electricity and non-electricity	4.0	2.0	1.0
ELCO	Other fuels and coals	4.0	2.0	1.0
ELFU	Other fuels (including biomass)	4.0	2.0	1.0

* Except for the energy sectors where the substitution parameter is zero.

Notes

1. We are sceptical of this claim, see Section 5.
2. The Baltic States (Lithuania, Latvia, Estonia) could not be added to the enlarged EU region because they are integrated into the FSU region in the GTAP-5E database. Cyprus and Malta could also not be added to the EU, as they are integrated in RoW in the GTAP-5E database. These omissions have little effect on the size of the carbon flows. The Baltic States emit less than two percent of the FSUs carbon dioxide emissions and the Baltic States plus Cyprus and Malta emit only about one percent of the carbon dioxide emissions of EU28.
3. The model that was used for the present simulations plus relevant data and parameter files can be found on URL: http://130.37.129.100/english/o_o/instituten/IVM/research/ihdp-it/implementation/index.htm.
4. EU28 is almost identical to the IEA region "OECD-Europe", except for the EU28 member states Bulgaria, Romenia and Slovenia who are not part of OECD-Europe. In terms of energy use and CO_2 emissions this difference is insignificant. The WEO2002 projections for OECD-Europe are therefore used for EU28 projections in this paper.
5. IEA (2002) presents projections for 'Transition Economies' and for 'Russia', but not for the FSU. The region 'Transition Economies' includes more countries than those belonging to the FSU, while 'Russia' includes fewer countries. The difference between the forecasts of annual rates of economic growth between 'Transition Economies' and 'Russia' is not big: 3.1 per cent for 'Transition Economies' against 3.0 per cent for 'Russia'. For our projections for FSU we make use of the WEO2002 projections for 'Transition Economies'.
6. See Poussenkova (*this issue*) for an interesting discussion on the economics and politics of the Russian energy sector. Under discussion in Russia is the option to increase the share of coal in electricity and heat production and sell more gas abroad. Domestic gas prices in Russia (including non-payment) are way below world market prices.
7. EU28 could also subsidize other form of renewable energy production. The limitation to biomass is due to the limitations of our model.
8. Note that we assume a perfect market for emission credits, i.e. a market subject to the Law of One Price. Under which legal regime the credits are traded, be it Joint Implementation, Emissions Trading or a combination of both, is of no concern to us in the present analysis.
9. Figure 1 does not show flows of biomass, as they are too small to be detectable.
10. Allowed emissions are 30 percent lower than 1990 emissions, which is 70% of 1990 emission (= 846 MtC).
11. It is well known, of course, that alternative rebate schemes may produce different welfare effects. We do not pursue this issue here, however.

12. Huntington and Brown (forthcoming) do not take these initial taxes into account. Preliminary calculations with GTAP-E (not reported here) suggest that, for the EU at least, the welfare effects of differentiating carbon taxes over fuels according to their import shares may be (very) negative.
13. For an instructive discussion on emissions trading and capital flows, see McKibbin et al. 1999.
14. The money metric used to assess the welfare costs is the "equivalent variation", i.e. the sum of money that would leave people indifferent between their initial situation and their situation after the policy change.
15. Exchange rate used between Euro and USD is: 1.13 $/€ (average exchange rate for 1997).

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